PB90-132697

Acid Fog Effects on Conifer Seedlings

(U.S.) Corvallis Environmental Research Lab., OR

1989

U.S. Department of Commerce
National Technical Information Service
NTIS

ERL-COR- 952D

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before complete)

1. REPORT NO. EPA/600/D-89/196	2.
3.	PB90-132697
4. TITLE AND SUBTITLE: Acid fog effects on conifer seedlings	5. REPORT DATE
	6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S): David P. Turner, David T. Tingey, and William E. Hogsett	8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS: US EPA, ERL-Corvallis, OR	10. PROGRAM ELEMENT NO.
	11. CONTRACT/GRANT NO.
12. SPONSORING AGENCY NAME AND ADDRESS: US Environmental Protection Agency, Environmental Research Laboratory, 200 SW 35th Street, Corvallis, OR 97333	13. TYPE OF REPORT AND PERIOD COVERED: Symposium paper
	14. SPONSORING AGENCY CODE: EPA/600/2

15. SUPPLEMENTARY NOTES: Air Pollution and Forest Decline (J.B. Bucher and I. Bucher-Wallin, eds). Proc. 14th Int., IUFRO P2.05, Interlaken, Switzerland, Oct. 2-8, 1988. Birmensdorf, 1989 p. 125-129.

16. ABSTRACT

Experiments were performed to assess the effects of acid fog on foliar injury, biomass production, and nutrient leaching in selected conifers. One-year old seedlings of Pseudotsuga menzieii, Pinus ponderosa, Tsuga heterophylla and Thuja plicata were exposed episodically to fog events of variable duration (22 events over a 60 day period for a total of 93 hr). Exposures occurred in open top chambers with fog acidified to pHs of 2.1, 3.1 or 5.6. Foliar injury was observed only in T. heterophylla (pH 2.1 and 3.1) and T. plicata (pH2.1). The low pH fog treatments significantly reduced root biomass in T. heterophylla and across species there was a trend towards a reduced proportion of total dry weight as roots with decreasing fog pH. A concurrent experiment examined foliar leaching in P. menziesii. Seedlings were grown in solution culture at two levels of nutrient availability and exposed to pH 5.6 or pH 3.1 fog (24 events over an 84 day period for a total of 96 hrs). For seedlings at the higher level of nutrient availability, foliar leaching rates were determined by analyses of throughfall solutions and compared to root uptake rates (based on depletion from the nutrient solutions). Fog pH did not affect total biomass production or foliar nutrient contents. However, plant growth and foliar nutrient levels were higher in plants grown at the higher nutrient level. Foliar leaching (K > Ca > Mg) was greater with a pH. 3.1 fog than a pH 5.6 fog but the amounts leached (by a 4 hour pH 3.1 fog) were small compared to the daily uptake rates for these seedlings.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group

REPRODUCED BY
U.S. DEPARTMENT OF COMMERCE
NATIONAL TECHNICAL INFORMATION SERVICE
SPRINGFIELD, VA. 22161

18. DISTRIBUTION STATEMENT: Release to Public	19. SECURITY CLASS (This Report): Unclassified	21. NO. OF PAGES: 8
	20. SECURITY CLASS (This page): Unclassified	22. PRICE

EPA Form 2220-1 (9-73)

NOTICE

This document has been reviewed in accordance with U.S. Environmental Protection Agency policy and approved for publication. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

EPA/600/D-89/196

Air Pollution and Forest Decline (J.B. Bucher and I. Bucher-Wallin, eds.).
Proc. 14th Int. Meeting for Specialists in Air Pollution Effects on Forest Ecosystems,
IUFRO P2.05, Interlaken, Switzerland, Oct. 2-8, 1988. Birmensdorf, 1989, p. 125-129.

ACID FOG EFFECTS ON CONIFER SEEDLINGS

David P. Turner, David T. Tingey and W.E. Hogsett

Environmental Protection Agency
Corvallis, Oregon, U.S.A.

ABSTRACT

Experiments were performed to assess the effects of acid fog on foliar injury, biomass production, and nutrient leaching in selected conifers. One-year old seedlings of Pseudotsuga menziesii, Pinus ponderosa, Tsuga heterophylla and Thuja plicata were exposed episodically to fog events of variable duration (22 events over a 60 day period for a total of 93 hr). Exposures occurred in open top chambers with fog acidified to pHs of 2.1, 3.1 or 5.6. Foliar injury was observed only in T. heterophylla (pH 2.1 and 3.1) and T. plicata (pH 2.1). The low pH fog treatments significantly reduced root biomass in T. heterophylla and across species there was a trend towards a reduced proportion of total dry weight as roots with decreasing fog pH. A concurrent experiment examined foliar leaching in P. menziesii. Seedlings were grown in solution culture at two levels of nutrient availability and exposed to pH 5.6 or pH 3.1 fog (24 events over an 84 day period for a total of 96 hr). For seedlings at the higher level of nutrient availability, foliar leaching rates were determined by analyses of throughfall solutions and compared to root uptake rates (based on depletion from the nutrient solutions). Fog pH did not affect total biomass production or foliar nutrient contents. However, plant growth and foliar nutrient levels were higher in plants grown at the higher nutrient level. Foliar leaching (K > Ca > Mg) was greater with a pH 3.1 fog than a pH 5.6 fog but the amounts leached (by a 4 hour pH 3.1 fog) were small compared to the daily uptake rates for these seedlings.

INTRODUCTION

Coniferous trees on some coastal (Oberlander 1956) and mountainous (Vogelmann et al. 1968) sites spend significant periods in fog or clouds. These forests efficiently filter water from moisture laden air as it passes through the canopy (Lovett 1984). Concentrations of ions in fog or clouds tend to be higher than in rain (Wisniewski 1982) with fog pHs below 2.2 observed in heavily polluted areas (Waldman et al. 1985). In these cases, an interaction between the chemical constituents of the clouds and the physiology of the trees is likely (Huttermann 1985).

One or more of the following mechanisms related to tree mineral nutrition may be contributing to forest decline in areas of high acidic precipitation. (i) Hydrogen ions in fog or rain increase leaching of nutrient cations from either the foliage (Scherbatskoy and Klein 1983) or soil (Johnson et al. 1983), thus promoting nutrient deficiencies. (ii) Blockage of root uptake sites by solubilized Al+3 (Stienen and Bauch 1988) and site-specific factors such as low concentrations of nutrient cations in the parent material (Huttl and Wisniewski 1987) restrict uptake rates. (iii) Damage to epicuticular or cuticular wax layers of the foliage results in decreased control of water and ion movement out of the foliage. (iv) Nitrogen uptake from the fog either by the foliage or by roots (after drip from the canopy) creates nutrient imbalances (Nihlgard 1985). Alternatively, uptake may result in a growth enhancement (Aber et al. 1982).

The objectives of this research were to screen four coniferous species of the western United States for the effects of acidic fog on growth characteristics (species comparison study) and to examine in more detail the impact of acidic fog on plant mineral nutrition (foliar leaching study).

MATERIALS AND METHODS

Plant Culture

One-year old seedlings of Pseudotsuga menziesii (Douglas-fir), Tsuga heterophylla (western hemlock), Thuja plicata (western redcedar) and Pinus ponderosa (Ponderosa pine) were obtained from a commercial nursery and cultured in potting soil with periodic addition of complete fertilizer until fog exposures began.

Species Comparison Study

The fog exposures occurred in modified open-top chambers (Hogsett et al. 1985) under natural environmental conditions (March-April 1987, Corvallis, OR) and employing a simulated ambient exposure regime. Selection of the simulated ambient exposure regime for acidic fog was based on fog chemistry (pH and ion concentrations), as well as temporal dynamics, of selected regional fog events. Start times, fog duration, and fog frequency were based on fog occurrence data from two sites representative of the coastal West. Over the 60-day exposure period, there were 22 events occurring episodically and of variable duration. The total acid fog exposure was 93 hr. The pH and ion concentrations of the pH 3.1 experimental treatment are near the median values reported for Henninger Flats, a southern

California site with relatively severe air pollution (Waldman et al. 1985). Additional experimental treatments of pH 2.1 (extreme observation) and pH 5.6 (control) were created by increasing or decreasing the ion concentrations, but keeping the nitrate to sulfate ratio approximately 2:1. Mean mass particle size (evaluated with a Particle Measuring Systems CSASP-100-HV-SP optical particle counter) of the fog aerosols was 33 microns.

Visual needle damage was evaluated following the final exposure day and seedlings were allowed to grow on through the spring and summer to assess time of bud break and bud elongation. Root, total needle and stem dry weights were determined at the end of the growth period (summer 1987). Ten trees were tested per treatment. Treatment comparisons were made on natural log-transformed data using analysis of variance and the Bonferroni multiple comparison test (Neter and Wasserman 1974) with a minimum p of .05. An arcsin transformation was used for the proportion of total dry weight as roots.

Foliar Leaching Study

Plant material and fog chemistry for the foliar leaching study were the same as in the species comparison study but only Douglas-fir and the pH 3.1 and pH 5.6 fog treatments were used. Plants were cultured in the fog chambers, which were located within a greenhouse, and supplied with charcoal filtered air. Fog treatments were applied for four hours twice weekly for 12 weeks.

Seedlings were grown in solution culture in order to control nutrient availability and to measure nutrient uptake rates. Two levels of nutrient availability were used so that the effect of nutrient availability on seedling response to the fogs could be evaluated. Nutrient uptake rates were measured under the higher level of nutrient availability for comparison with foliar leaching rates under the same conditions. Determination of foliar leaching rates and root uptake rates (see below) for calcium (Ca), magnesium (Mg) and potassium (K) were made throughout the duration of the experiment. At the end of the exposures, seedlings were harvested for determination of root and shoot dry weights and nutrient concentrations (Ca, Mg and K) in first and second year foliage. Much of the second year foliage was formed during the 12-week exposure period.

The solution culture system was designed so that each seedling was maintained in a continuously aerated cylindrical vessel (1L) with circulation to a large nutrient reservoir shared with four adjacent seedlings. Nitrogen concentration of the first treatment ("low") was 1.0 ppm (0.6 ppm NO3-N and 0.4 ppm NH4-N) with element to nitrogen ratios as recommended by Ingestad (1979). Concentrations of all elements in the second treatment ("moderate") were an order of magnitude higher (6 ppm NO3-N and 4 ppm NH4-N). The 10 ppm N in the moderate treatment is low relative to concentrations used in the Ingestad (1979) experiments, but it was adequate for rapid growth under these experimental conditions. Nutrient solutions were changed every two weeks and additions of NaOH were used to keep nutrient solution pH above 4.0. Temperatures of the nutrient solutions were maintained several degrees centigrade below air temperature and did not rise above 25 degrees centigrade.

Uptake rates (ug/plant/day of Ca, Mg and K) for seedlings with the moderate nutrient regime were determined by analysis of the depletion of nutrients from the 20 L reservoirs over a 2 week period. In the low nutrient regime, concentrations in the nutrient solutions fell below detection limits soon after each nutrient change so uptake rates could not be measured.

Canopy leaching rates (ug/plant/fog event for Ca, Mg and K) were also determined for seedlings in the moderate nutrient regime. Rates were based on throughfall (drip + stem runoff) volumes and changes in concentration between fog stock solutions and throughfall solutions (less changes in a control collection system). For each seedling, throughfall was collected by a polyethylene funnel fitted around its base. Drainage lines delivered the throughfall to capped sample bottles adjacent to the tree seedlings.

Within each of four chambers (two per pH regime) there were two sets of five trees (one set per nutrient regime). Thus, for leaching rate and foliar nutrient concentrations, each pH x nutrient regime was tested by 10 replicate plants. Analyses of all solutions and plant digests for Ca, Mg and K were made by inductively coupled plasma analysis (McQuaker et al. 1979). Treatment comparisons were made using analysis of variance.

Surfaces and cross sections of first year needles (i.e. those fully formed before the fog exposures began) from seedlings exposed to the two fog treatments were examined by scanning electron microscopy soon after harvesting to check for damage to epicuticular and cuticular wax. Needles were air dried and coated with a 60/40 gold palladium alloy by vacuum evaporation before analysis in an Amray 1000A scanning electron microscope.

RESULTS

Species comparison study

Acid fog induced visible foliar injury only in western hemlock (pH 2.1 and 3.1) and redcedar (pH 2.1). The necrosis was dark bronze in color in hemlock, whereas in redcedar (pH 2.1), necrosis appeared light orange. The injury started as tip necrosis and in some cases proceeded to fully necrotic needles.

For ponderosa pine, Douglas-fir and western redcedar, the highest foliar and root tissue dry weights occurred with the pH 3.1 fog treatment (Figure 1), although the within-species differences were not statistically significant. There was a significant decrease in the root dry weight of western hemlock with the lower fog pHs (Figure 1). Across species, there was also a small but significant pH effect on the proportion of total dry weight as roots, which decreased as fog pH decreased (Figure 2).

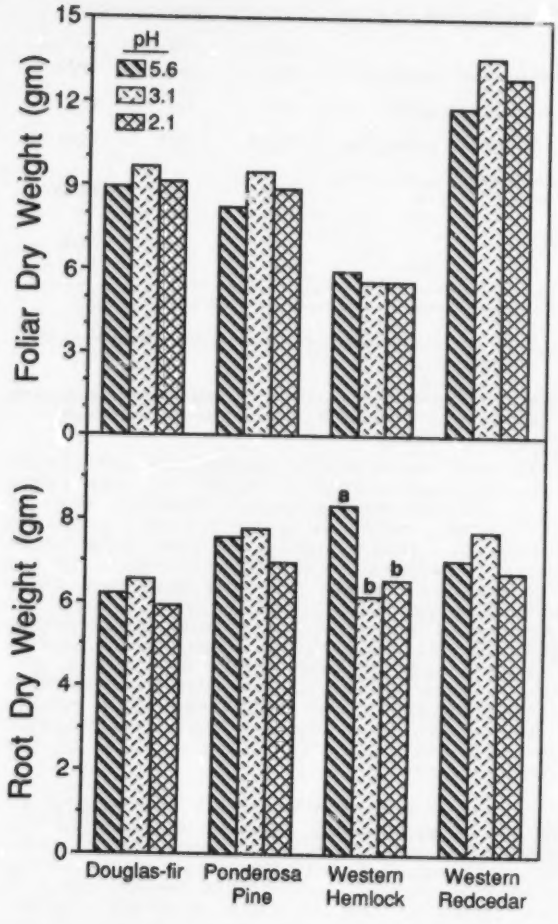

Figure 1. Mean dry weight after fog exposure for foliage and roots of four coniferous tree species, the same letter or no letter within a species and tissue type indicates no significant difference ($p \geq 0.05$).

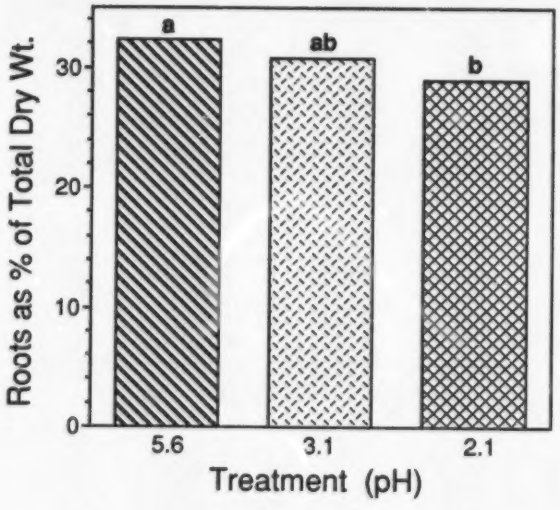

Figure 2. The influence of fog pH on the proportion of total dry weight that was root, averaged across the four species. The same letter across columns indicates no significant difference ($p \geq 0.05$).

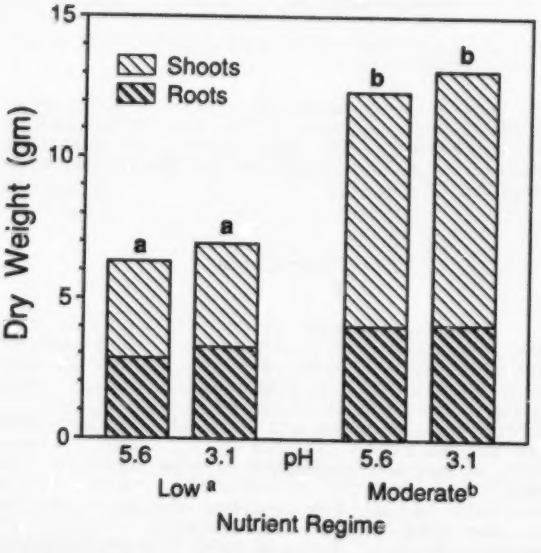

Figure 3. Dry weight of roots and shoots for Douglas-fir after fog exposures. The same letter across columns indicates no significant difference in total dry weight ($p \geq 0.05$). Letter adjacent to the nutrient regimes indicates the significance of an overall nutrient treatment effect.

Foliar Leaching Study

The total biomass and the concentrations of K and Mg in first and second year foliage were significantly higher in the moderate nutrient regime than in the low nutrient regime (Figures 3 and 4). In agreement with the results for Douglas-fir in the species comparison study, there were no significant effects of fog pH on tissue dry weights (Figure 3). Likewise, nutrient concentrations in first and second year foliage were similar across fog pH treatments (Figure 4).

Results for leaching and uptake rates are given for a fog event and an uptake period midway through the 84 day study (Table 1). Leaching rates for Ca, Mg and K were greater for a pH 3.1 fog than the pH 5.6 fog, with potassium being most readily leached. The amounts leached, however, were small relative to amounts in the foliage and in the total seedling (Table 1). Within the moderate nutrient regime there were no significant differences in uptake rates (data not shown) or final root dry weights (Figure 3) between seedlings exposed to the different pH fogs. Results for uptake were therefore pooled across the fog pH treatments. Under the moderate nutrient regime, daily root uptake rates were much greater than the leaching rates associated with either pH 5.6 or pH 3.1 fogs (Table 1).

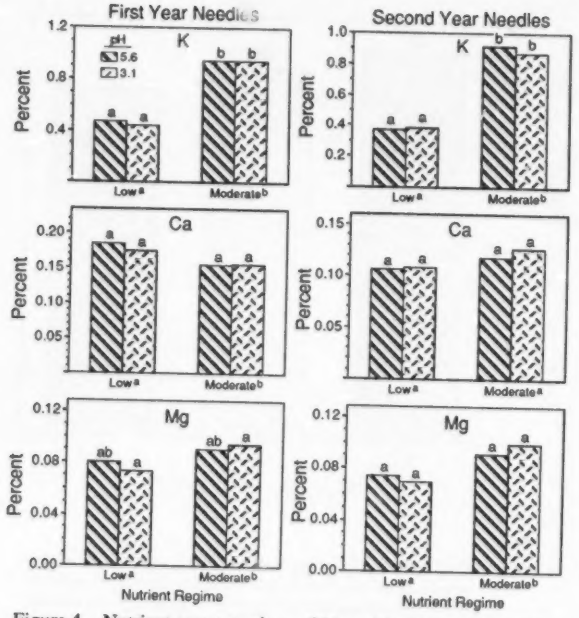

Figure 4. Nutrient concentrations of 1st and 2nd year foliage for Douglas-fir after fog exposures. Within an element, the same letter across columns indicates no significant difference ($p \geq 0.05$). Letters adjacent to the nutrient regimes indicated the significance of an overall nutrient treatment effect.

Analysis by scanning electron microscopy of first year needles at the end of the leaching experiment did not reveal conspicuous erosion of epicuticular or cuticular wax as a function of fog pH.

DISCUSSION

The observations of foliar injury in the species comparison study suggest that hemlock and redcedar are more sensitive to low pH fogs than Douglas-fir and ponderosa pine. This pattern may be a function of foliar characteristics that promote and maintain contact with the fog solution (Haines et al. 1985) Hemlock stems are pubescent; the needles are small and tightly clustered. Thus, large droplets having low contact angles with the foliage tend to form and persist. Sprays of western redcedar foliage have a flat orientation and the depressions between adjacent foliar subunits collect and retain moisture. In contrast, the surfaces of Douglas-fir and Ponderosa pine foliage are smooth and droplets retain high contact angles. A positive correlation between acid-precipitation induced foliar injury and foliar wettability has been observed in a number of other plant species (Haines et al. 1985).

The results of the leaching study indicate that foliar leaching by the pH 3.1 fogs is not likely to generate foliar nutrient deficiencies. In this experiment, the twice weekly fogs did not reduce foliar nutrient concentrations in either the low or moderate nutrient regimes. With the moderate nutrient regime this result is related to compensatory uptake. Good aeration (Bledsoe and Rains 1981) and rapid mixing associated with solution culture probably result in relatively high nutrient uptake rates. However, even if the uptake rates were halved and leaching rates were doubled the tree seedlings could still compensate for leaching losses. In the low nutrient regime, the tree seedlings under both fog pHs were clearly under nutrient stress, as evinced by small biomass increases and chlorotic coloration. Under conditions of a restricted nutrient supply to the foliage, the failure of the low pH fogs to draw down foliar nutrient concentrations of a mobile element such as K suggests that intracellular nutrient pools were not being affected by the fog exposures.

Table 1. Pool sizes, rates of foliar leaching, and rates of root uptake.

		Ca	Mg	K
Plant Pool Size[1]	µg/tree	9222	2502	15572
Foliar Pool Size[1]	µg/tree	4170	1297	9142
Uptake Rate[2]	µg/tree/24 hr	114±16	78±9	964±117
Leaching Rate[3]	µg/tree/4 hr fog			
pH 3.1	µg	20±9	18±4	63±20
	µeq	1.0	1.5	1.6
pH 5.6	µg	9±5	2±1	19±12
	µeq	0.5	0.2	0.5

1. Based on dry weights and tissue concentrations before fogging.

2. Mean and standard deviation (n=4) for all sets of trees under the moderate nutrient regime.

3. Mean and standard deviation for a 4 hr fog event (trees under the moderate nutrient regime). For K and Mg, differences between fog pHs were significant ($p \leq 0.05$).

The proportion of total dry weight as roots is apparently readily shifted in response to nutrient availability. In the foliar leaching study this proportion was 0.46 for seedlings in the low nutrient regime and 0.32 for those in the moderate nutrient regime. Fertilization of roots (the soil surface was not protected from the fog) or shoots by the low pH fog (high ion concentration) in the species comparison study may account for the observed decrease in the proportion of total dry weight as roots. In the field, if acidic fog reduced the proportion of total dry weight as roots, trees could be sensitized to nutrient and water stress.

The magnitude of fog induced leaching was relatively small in the foliar leaching study. Ions leached from a forest canopy by acidic fog would, in any case, re-enter the soil nutrient pools and become available for uptake by the trees at a small metabolic cost (Amthor 1986). However, the situation is much more complicated in a forest subjected to a high pollution load because foliar leaching may be accelerated by interactions with other pollutant stresses and nutrient uptake may be restricted by various mechanisms associated with soil acidification.

ACKNOWLEDGMENTS

The research was supported by funds provided by the Western Conifers Research Cooperative with the joint U.S. Environmental Protection Agency-USDA Forest Service Forest Response Program.

REFERENCES

Aber, J.D., Hendry, G.R., Francis, A.J., Botkin, D.B., and Melillo, J.M. 1982. Potential effects of acid precipitation on soil nitrogen and productivity of forest ecosystems. In: Acid Precipitation. F.M. D'Intri (ed). Ann Arbor Science, Ann Arbor, MI. pp 411-433.

Amthor, J.S. 1986. An estimate of the 'cost' of nutrient leaching from forest canopies by rain. New Phytol. 102:359-364.

Bledsoe, C.S., and Rains, D.W. 1981. Cation uptake by Douglas-fir seedling grown in solution culture. Can. J. For. Res. 11:812-816.

Haines, B.L., Jernstedt, J.A., and Newfeld, H.S. 1985. Direct foliar effects of simulated acid rain. II. Leaf Surface characteristics. New Phytol. 99:407-416.

Hogsett, W.E., Tingey, D.T., and Holman, S.R. 1985. A programmable exposure control system for determination of the effects of pollutant exposure regimes on plant growth. Atmos. Environ. 19:1135-1145.

Huttermann, A. 1985. The effects of acid deposition on the physiology of the forest ecosystem. Experientia 41:584-590.

Huttl, R.F., and Wisniewski, J. 1987. Fertilization as a tool to mitigate forest decline associated with nutrient deficiencies. Water, Air and Soil Poll. 33:265-276.

Ingestad, T. 1979. Mineral nutrition requirements of Pinus sylvestris and Picea abies seedlings. Physiol. Plant. 45:373-380.

Johnson, D.W., Richter, D.D., Van Miegroet, H., and Cole, D.W. 1983. Contributions of acid deposition and natural processes to cation leaching from forest soils: a review. J. Air Poll. Cont. Assoc. 33:1036-1040.

Lovett, G.M. 1984. Rates and mechanisms of cloud water deposition to a subalpine balsam fir forest. Atmos. Environ. 18:361-371.

McQuaker, N.R., Kluckner, P.D., and Chang, G.N. 1979. Calibration of an inductively coupled plasma-atomic emission spectrometer for analysis of environmental materials. Anal. Chem. 51:888-895.

Neter, J., and Wasserman, W. 1974. Applied Linear Statistical Models. Richard D. Irwin, Inc. Homewood, Illinois.

Nihlgard, B. 1985. The ammonium hypothesis--an additional explanation to the forest dieback in Europe. Ambio 14:2-8.

Oberlander, G.T. 1956. Summer fog precipitation on the San Francisco peninsula. Ecology 37:851-852.

Scherbatskoy, T., and Klein, R.M. 1983. Response of spruce and birch foliage to leaching by acidic mists. J. Environ. Qual. 12:189-195.

Stienen, H., and Bauch, J. 1988. Element content in tissues of spruce seedlings from hydroponic cultures simulating acidification and deacidification. Plant Soil 106:231-238.

Vogelmann, H.W., Siccama, T., Leedy, D., and Ovitt, D.C. 1968. Precipitation from fog moisture in the Green Mountains of Vermont. Ecology 49:1205-1207.

Waldman, J.M., Munger, J.W., Jacob, D.J., and Hoffman, M.R. 1985. Chemical characterization of stratus cloudwater and its role as a vector for pollutant deposition in a Los Angeles pine forest. Tellus 37B:91-108.

Wisniewski, J. 1982. The potential acidity associated with dews, frosts, and fogs. Water, Air and Soil Pollution 17:361-377.